or less plausible guesses as regards the necessary mechanism, but the particular guess ventured upon by Mr. Maunder is not, I think, consistent with well established facts. I cannot, therefore, agree with his somewhat boastful claim that he has rendered clear what Lord Kelvin has called a "fifty years' outstanding difficulty." He has, no doubt, added a new fact and made an important contribution to the subject. He has given renewed interest to it and brought out the urgent importance of further investigation, but the mystery is left more mysterious than ever; the facts have become harder to understand and more difficult to explain.

Magnetic Storms and associated Sun-spots. By the Rev. A. L. Cortie, S.J.

The first and most important conclusion of Mr. Maunder's paper on "Magnetic Disturbances, 1882 to 1903, as recorded at the Royal Observatory, Greenwich, and their Association with Sun-spots" (*Monthly Notices, R.A.S.* vol. lxv. No. 1, 1904 November) is, that the origin of magnetic disturbances on Earth lies in the Sun, and not in any body or bodies affecting both. That is, that the Sun is the seat of the efficient cause of our magnetic storms, for evidently Mr. Maunder is not speaking of a mere condition. And the premisses for this conclusion are: first, that the magnetic storms mark out the synodical rotation-period of the Sun; and secondly, that what marks out the synodical rotation of the Sun must be caused by something in the Sun—this second premiss is implied, but not expressed, and is not necessarily true—therefore the cause of magnetic storms lies in the Sun. But the argument of Mr. Maunder is faulty, in that it omits at least one other alternative: namely, that both the magnetic storms on Earth, and the magnetic centres on the Sun associated with sun-spots, which are presented to the Earth at successive synodical rotations, may have a common cause which is neither on the Sun nor on the Earth. This latter alternative is consonant with the theory proposed by Father Sidgreaves in his memoir "On the Connexion between Solar Spots and Earth Magnetic Storms" (*Memoirs, R.A.S.* vol. liv. p. 91). For when two sets of connected phenomena are found regularly to concur, the logical conclusion is not necessarily that one is the cause of the other, but that either one is the cause of the other, or they have a common cause. It is this latter alternative of which Mr. Maunder has omitted to take account, and which renders his syllogism out of form. Therefore, even were he to prove his first premiss—namely, that magnetic storms mark out the synodic rotation-period of the Sun—up to the hilt, it would still not

follow logically that the cause of magnetic storms resides in the Sun.

There is no doubt that some positions of the Sun relatively to the Earth are more favourable conditions, and perhaps even necessary conditions of movements of the magnets, the "diurnal range" of the declination magnet, the "annual inequality," the greater prevalence of magnetic storms at the equinoxes, are abundant evidence of this. Nor, again, is there any doubt of the close connexion of magnetic storms with the spotted area and number of spots on the Sun. The laborious memoir of Father Sidgreaves (*loc. cit.*) and the papers of the Greenwich observers have shown this to be true, taking the spots in detail. This evidence is in addition to the statistical work of Mr. Ellis, which demonstrated the close accord of the variations of diurnal range of the declination and horizontal force magnets over a long period of years, with the curve of annual relative sun-spot numbers as prepared by Professors Wolf and Wolfer. But the same examination in detail of sun-spots and magnetic storms, made by Father Sidgreaves for the period 1881–1898, and by the writer for the minimum years 1899–1901 (*Astrophysical Journal*, vol. xvi. No. 4, 1902 November), has shown glaring exceptions to the general agreement of spots and magnetic storms, which precludes the possibility of the one being the cause of the other. If Mr. Maunder could completely prove his first premiss—and he only attempts to do so for at the most about 75 per cent. of the magnetic storms tabulated—the only conclusion that could be drawn would be, that the synodical rotation period of the Sun for middle latitudes, when sun-spots are present on his disc, is a favourable and perhaps necessary condition for magnetic storms on Earth. Professor Schuster has proved (*Report of the British Association*, Belfast, 1902, p. 518) that "the magnetic declination at Greenwich shows no period between 25·5 and 27·5 days having an amplitude as great as 6″," and Dr. Chree has shown (*Proc. R.S.*, vol. lxxi. p. 224) that Wolf and Wolfer's provisional curve of relative sun-spot numbers are matched by the curves of range of the magnetic elements, whether the sun-spot frequency curves be plotted for the magnetically "quiet" days only, or for all days, whether magnetically quiet or active. Therefore, so far as the diurnal range of the declination magnet at least is concerned—for Schuster's results deal only with this quantity—it follows that the synodical rotation period of the Sun does not affect the magnetic curve, and, on the other hand, that the curve of sun-spot frequency is independent of magnetic storms. But if Mr. Maunder's contention is correct, that greater sun-spots mark magnetic centres of activity on the Sun, which are so effective, and almost exclusively so on the Earth, that magnetic storms mark out the synodical rotation period of the Sun, then, on the one hand, the synodical rotation period of the Sun ought to be reflected in the curve of diurnal range of the declination magnet, which it is not, and, on the other

hand, the curve of relative sun-spot frequency should not be almost identical for "quiet" and all magnetic days, which it is.

To come now to Mr. Maunder's major premiss, that magnetic storms mark out the synodic rotation period of the Sun, in at least fifty per cent. of the cases observed. The chief evidence for this statement is set forth in Table III. of his paper; and as it is impossible at present to examine every sequence set down in the table, it is proposed to take the first and the second, and incidentally the fourth and the twenty-third, as also the thirty-second, for more detailed criticism. This last sequence is selected because it is claimed, in the first place, that it connects six storms which occurred in successive synodical rotations of the Sun, and in the second place because it includes two magnetic storms which, as Father Sidgreaves pointed out occurred at an epoch of minimum solar activity, when the Sun had been almost absolutely free from spots and faculæ for a considerable period. Table A of Father Sidgreaves' paper (*loc. cit.* p. 93) gives an example of the method in which the relation of sun-spots and magnetic storms was studied at Stonyhurst; and if the various sequences of Mr. Maunder's paper are studied in relation to the spots with which they were presumably connected, it will appear doubtful, whether the sequences in many cases might not be purely fictitious, so far at least as they are associated with sun-spots.

The first sequence in Mr. Maunder's list is connected with groups 53 and 53a of the Stonyhurst series, the life-history of which is given in the annexed chart. It is well to state here that the materials which have been utilised in the present discussion were prepared by Father Sidgreaves for his memoir. A summary history of these groups is also to be found in my paper on "The Duration of the Greater Sun-spot Disturbances for the Years 1881–99" (*Monthly Notices*, *R.A.S.* vol. lx. No. 8), the numbers of the groups here discussed tallying with those in Table I. of that paper.

These two associated groups, one being the recurrence of the other, persisted for five solar rotations. During the first rotation there were five days which were magnetically disturbed, the first storm occurring when the spot had just passed the central meridian. Four more days of magnetic disturbance occurred while the spot-group was on the invisible hemisphere of the Sun. During the second rotation there were only two magnetic storms: one did not coincide with any of the five days of magnetic disturbance of the first rotation, the other did. Surely such a coincidence is merely accidental. However, there is this fact in favour of a real synodical rotation coincidence, that the two storms that did coincide were the greatest of the whole series. Let it be supposed then that these two storms, one of the first and the other of the second rotation, mark out a magnetically active region of the Sun associated with the sun-spot. The sun-spot group returned

Chart I.

Sun-spot Group 53 *and Associated Magnetic Disturbances. Sequence I.*

M = Magnetic Storm Magnitude. S = Spot Magnitude.

C = Central Meridian. Ci = Central Meridian on Invisible Side. E, W = East and West Limbs.

1892.		Ci.						E.						C.						W.						Ci.		Spot Number. Stony-hurst.	Green-wich.
July			$^{\rm b}$[28]	29	30.	1	2	3	4	5	6	7	8	9	10	11.	12	13	14	15	16	17	18	19	20	21	22	23	July		
M.															3	4	5.			11.*	8			3					53	2581.
S.								13	16	18	24	22	20	20	15.	15	15	11	13	4										
July			24	25	26	27	28	29	30	31.	1	2	3	4	5	6	7	8	9	10	11	12	13.	14	15	16	17.	18	Aug.		
M.				3	3	3								3								9*								53	2611.
S.									3	12	10	8	9	9	7	5	5	4	5	4	4										
Aug.		19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Sept.		
M.																														53.	2643
S.									2	2	3	3	3	2	2	2	2	3	2	2	2	1									
Sept.	15.	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	Oct.		
M.							4	4																		3		3		53.	2675
S.									1	1	1	1	1	1	2	3	2	2	1	1	1										
Oct.		13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6			Nov.		
M.		3	4	3		*3	3																	6						53a	2718.
S.																		1	1	0·4	0·1										

* Reference numbers of disturbances: Maunder, 151, 154, 156.

Mean heliographic coordinates, Group 53 ; long. 91°, lat. +11°.
53a ; long. 94°, lat. +11°.

Spot-group probably born on June 28.

CHART II.

Sun-spot Group 29 and Associated Magnetic Disturbances. Sequences II., IV., and beginning of XXIII.

1886.		Ci.						E.						C.						W.							Ci.		Spot Number. Stonyhurst.	Greenwich.
Mar.			23	24	25	26	37	28	29	30	31.	1	2	3	4	5	6	7	8	9	10	·11	12	13	14	15	16	17	April		
M.			3						10	7	5.											†3	3	3	4			3		29.	1861
S.									0·3	0·4	0·4	1	1	2	2	2	2	3	1	1											
Apr.			18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	May		
M.			3	3																			†6	3	3	3				29.	1878.
S.														1	1	2	8	9	9	10	9										
May		14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	June		
M			3																											29	1884
S.									3	4	4	4	3	3	4	3	3	3	3	3	2										
June		10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	July		
M.													3								*									29.	1897.
S.									3	3	2	2	2	1	1	1	1	1	1	0·2											
July	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31.	1	2	3	Aug.		
M.																					7*									29.	1906.
S.									0·4	1	2	4	4	5	5	6	4	5	3	2											
Aug.			4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	Aug.		
M.													3									4*								29.	1915.
S.										1	1	1	1	1	1	1	1	0·4	0·2												
Aug.	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18									Sept.		1924
M.											§3	3	3		3															29.	
S.												0·4	0·4	1	1	1	1.														1925

Reference numbers of disturbances: Maunder *, 72, 73, 74. † Numbers 69, 70. § 75. Mean heliographic coordinates, long. 71°, lat. −10°.

for three more rotations, diminished in size it is true, and the magnetic centre ceased to act. And yet in other cases, notably in those of 1889 November, we are to suppose, in order to form a sequence, that a magnetic centre can be active, not only during the life-history of a sun-spot group, but long after all spots to mark the magnetic centre of storms have disappeared. This is anomalous. Moreover, though this particular sun-spot group was diminished in size, it could still be magnetically active, on the supposition that these sequences of magnetic storms were connected with the sun-spot, for in the fourth rotation, when it came to the E. limb, another active storm occurred (omitted from Mr. Maunder's list), which forms an equally good sequence with No. 156 of his Table I.—which occurred at the fifth appearance of the region of the spot on the E. limb—as is formed by numbers 151 and 154, marking the W. limb position. On the supposition of a stream-like set of particles emanating from the spot and impinging on the Earth to cause sequences of magnetic storms, it is difficult to imagine how both an E. limb and a W. limb, as well as a central, position of the spot, could be effective. This second sequence, too, seems to accentuate the non-activity of the region of the first sequence during the third and subsequent rotations. It fact it would seem that the magnetic storms set down in the chart have very little connexion with the spot. The most active period of the life-history of the spot, too, is marked by a storm which does not recur.

The next spot-group dealt with is that numbered 29 in the Stonyhurst lists, the details of its life-history and the associated magnetic storms being set down in the subjoined chart.

The visible duration of this sun-spot group was 170 days, and it passed the central meridian seven times. Appearing on the E. limb on 1886 March 29 as a small insignificant group, its first appearance was announced by the greatest magnetic storm of any that occurred during its life-history, and, indeed, the greatest magnetic storm of the year. The storm began with the sharp movements in the magnets characteristic of many great storms. Its number in Mr. Maunder's list is 68, and it is not a member of any of the sequences in Tables III. and VI. The spot, the advent of which it marked upon the disc, came round five more times, and this presumed focus of violent magnetic action which affected the Earth at the first rotation fails to affect it at the five succeeding rotations. But when at the seventh rotation two groups of very small spots marked the position of the former group, the region again becomes magnetically active and gives the first storm of Mr. Maunder's sequence XXIII.—the connexion being adverted to in Table VIII. of Mr. Maunder's paper—the other three members occurring at a time when solar activity, as shown by spots and faculæ, had suffered a marked diminution. This mode of action is again anomalous if sun-spots fix the magnetically active regions of the Sun. For it is difficult to explain why a violently active magnetic region

should have been quiescent for five rotations, to break out again when all spots had disappeared. Mr. Maunder in his paper appeals to intermittent action both of spots and magnetic storms, and gives examples of the one in Tables IV. and V., and of the other in Table VII. This appeal to intermittent action would have been stronger had he been able to show that the intermittent magnetic storms were associated with intermittent appearances of spots. The life-history chart of the present solar disturbance contains two other sequences, viz. II. and IV., of Mr. Maunder's paper. Sequence II. is marked by three storms, according to his enumeration, but by two only according to the Stonyhurst lists, which are determined by W. limb position of the spot. Here again one sequence marks the W. limb position, and another the E. limb position of the same spot region, and the same difficulty occurs, as was mentioned above, of a stream of particles in practically parallel lines, derived from the same active magnetic region, reaching the Earth when the spot was both on the E. and W. limbs. Sequence IV., also of two members, occurred when the sun-spot group 29 was on the invisible disc of the Sun, but the first member of the sequence is accredited to a sun-spot group, No. 28 of the Stonyhurst lists, which was visible for six successive rotations, and the second member probably belonged to a different sun-spot group altogether, No. 30 of our lists, which was visible for three rotations. Hence this concurrence to form a sequence seems to be fortuitous. There is also in this chart of group 29 a sequence of three magnetic storms which are not in Mr. Maunder's lists, and which are unconnected with any of the greater sun-spot groups of the year 1886. The result again of the study of the sequences associated with the life-history of this group serves to show, that although sequences undoubtedly exist, the nature of their connexion with the spot-groups, which are presumed to be indices of the regions of magnetic activity on the Sun, is not that of streams of particles of restricted diameter.

The sequence numbered XXXII. in Mr. Maunder's table is important, first, because it contains six members, and secondly, because it occurred at a time of minimum activity. By this sequence Mr. Maunder endeavours to connect the active magnetic storms of 1889 November with the second rotational appearance of the biggest spot of the year which was first seen on June 16. But in his table on p. 21 the longitude of the centre of the Sun's disc has altered from 57°·0 at the beginning of the sequence to 108°·8 at the end of the sequence. This in itself is internal evidence that the members of the sequence are only fortuitously connected, and do not mark the same magnetic region on the Sun. On pp. 29 and 30 Mr. Maunder discusses the life-history of the groups on the Sun when the first of these disturbances appeared. But besides the two groups of spots he mentions in longitude 35°, latitude −7°, and longitude 82° and

latitude $-8°$ respectively, there was a third group, Stonyhurst number 42, which was on the central meridian four times, the Greenwich numbers of the spots being 2097, 2100, and 2102, 2103, 2107 for each successive rotation. It is with this spot-group that the storm of October 5—the fourth of the sequence—was certainly connected, the mean heliographic coordinates of the group being longitude 156°, latitude $-22°$. There is also quite a possibility of the second and third members of the sequence having belonged to the same spot-group. However this may be, the attempt to connect the November magnetic storm with the one great spot outburst of the year breaks down. The spots are separated 120° in longitude, and do not mark the same magnetic centre. In the Stonyhurst lists the several storms of this sequence are accredited to three spot-groups, No. 40, long. 35°, lat. $-7°$, No. 41, long. 82°, lat. $-8°$, No. 42, long. 156°, lat. $-22°$. The progressive longitudes of these three groups must be noted, which explains the similar progressive longitude of the centre of the Sun's disc for the various members of sequence XXXII., and therefore shows that they belong to different sun-spots. Mr. Maunder has failed to catalogue an active magnetic storm of 1889 November 17, which would give a storm occurring between the fifth and sixth members of the group when the same meridian was turned directly away from the Earth. It makes the sequence less strong than it would otherwise have been. Again with regard to this particular sequence Mr. Maunder claims (*loc. cit.* p. 23) that it is one of those that indicate a much more rapid rotation of a solar zone of latitude than the mean period 25·38 days, and it does so because the sequence marks a latitude of magnetic activity in the Sun which is near the solar equator. This point he alludes to as "exceedingly important." If Mr. Maunder could prove that the sequence was formed of members that marked a magnetically active region connected with the June spot of 1889 in latitude $-7°$ it would go far to establish his point. But in the sequence the October magnetic storm is certainly connected with the spot in latitude $-22°$, and the two November storms form a sequence with this storm, and only casually with the other members of the group. Now the rotation period of latitude $-22°$ is much slower than that of latitude $-7°$. It follows, therefore, that the rotation period derived from the series of six magnetic storms, by a mean which includes storms in relatively high and low latitudes, is fictitious, and is not related to the corresponding equatorial zone of sun-spots.

As far, then, as this detailed examination of the sequences connected with the synodic rotation period of the Sun has gone, it shows that the sequences in several cases are real, but that the association of sun-spots with the presumed magnetic centres giving rise to the several sequences is not a very close one. But if it be claimed that the association with sun-spots is a close one, then the mode of action of the magnetic centres by means of

streams of particles, practically parallel, and of relatively small diameter impinging on the Earth is negatived. Such a stream of particles could not be effective at positions so remote from each other as the E. and W. limbs of the Sun.

Stonyhurst College Observatory,
January 1905.

Observations of the Spectra of Sun-spots, Regions C to D.

By A. Fowler.

Introductory.

The observations of the spectra of sun-spots forming the subject of the present paper were made somewhat irregularly during the period 1903 October 15 to 1904 December 31 Detailed observations of widened lines were made on twenty-three separate days, and fifty-three observations of the appearance of the C line in and near spots were made on thirty-five days. The observations were restricted almost exclusively to the red end of the spectrum between C and D_2, and as many as possible of the affected lines in this region were recorded. They are therefore comparable with the observations made by Father Cortie at Stonyhurst,* and the results are of some interest as showing the degree of agreement between two independent observers working on essentially the same plan. It is possible also that some points in the discussion of the observations which I have attempted may be suggestive to other observers.

Mode of Observation.

All the observations were made with an "Evershed" two-prism solar spectroscope by Hilger, attached to the 6-inch Troughton equatorial provided for the instruction of students at the Royal College of Science, South Kensington. The definition of the spectroscope is remarkably good, and the dispersion is adequate for the identification of most of the lines. There are of course many close doubles which cannot be clearly resolved with this equipment; but if such were widened the affected component could often be judged by noting on which side the widening seemed to lie; in other cases it remains doubtful which of the components was affected.

The approximate positions of the lines were read off from Rowland's map in the usual manner, and were afterwards corrected to two places of decimals by reference to the tables of solar lines.

* *Mem. R.A.S.* vol. l. pp. 30–56; *Monthly Notices*, vol. lxiii. pp. 468–480. Summarised in *Astrophys. Jour.* vol xx. pp. 253–265.